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The Refractive Index and Dispersion of Light in Argon and Helium.

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The initial object of this research was to find the dispersion of light in the monatomic gases argon and helium, but as it was necessary to know the absolute value of the refractive index with considerable accuracy, determinations of the refractive index have also been made. Their relative refractive powers (air = 1) have been found by Rayleigh,* and Ramsay and Travers,† using coloured interference fringes, but no determinations of the absolute refractive index for light of given wave-length have hitherto been made.

The interferometer method due to Jamin was used. A horizontal beam of parallel white light was incident on the first Jamin plate. The two reflected beams traversed two brass tubes of equal length closed by equal thicknesses of worked plane glass. Each brass tube had a small side tube attached which led to apparatus for altering the density in the tube and measuring its pressure. After reflection at the second Jamin plate, the recombined beam was focussed on the slit of a spectrometer, the spectrum obtained with a plane diffraction grating was examined through the telescope of the spectrometer and was seen crossed by bands of maximum and minimum intensity. At the same time, by means of a small reflecting prism, a portion of the slit was illuminated by the light from a Plücker tube containing hydrogen, helium, and mercury vapour. Thus one observed simultaneously the interference bands and certain standard lines of known wave-length with any one of which the cross wire of the telescope could be brought into coincidence.

Refractive Index.—The refractive index (n_0) of a gas at 0° C. and 760 mm. pressure for light of wave-length λ is given by $n_0-1 = (1+\alpha t) \,.\, 76 \,.\, \dfrac{f\lambda}{\text{PL}}$, where $t°$ C. is the temperature, α is the coefficient of expansion, f is the number of bands which move over the standard line of wave-length λ as the pressure changes by P cm., and L is the length of gas path in the tube.

The values of λ and L are determined once for all, and those of f, P, t are

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* Rayleigh, 'Roy. Soc. Proc.,' vol. 59, p. 203.

† Ramsay and Travers, 'Roy. Soc. Proc.,' vol. 64, p. 190, and vol. 67, p. 331.

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observed in each experiment as described below. The gas laws are assumed to hold for argon and helium over the limited ranges of pressure and temperature used, and α is taken as equal to 0·00367.

Dispersion.—

Let λ and λ' be the wave-lengths of two standard lines,
n and n' the corresponding refractive indices under pressure H,
n_1 and n_1' the corresponding refractive indices under pressure H_1,
δ the diminution in number of fringes between the standard lines when the pressure changes from H to a less pressure H_1.

If f be the number of bands crossing λ, then $f+\delta$ is the number of bands crossing λ', so that the difference of path introduced is

$$(n-n_1)\,\mathrm{L} = f\lambda,$$

and

$$(n'-n_1')\,\mathrm{L} = (f+\delta)\,\lambda'.$$

Thus

$$\frac{n'-n_1'}{n-n_1} = \left(1+\frac{\delta}{f}\right)\frac{\lambda'}{\lambda}.$$

Also, from Gladstone and Dale's law,

$$\frac{n-1}{\mathrm{H}} = \frac{n_1-1}{\mathrm{H}_1} = \frac{n-n_1}{\mathrm{H}-\mathrm{H}_1},$$

$$\frac{n'-1}{\mathrm{H}} = \frac{n_1'-1}{\mathrm{H}_1} = \frac{n'-n_1'}{\mathrm{H}-\mathrm{H}_1}$$

Substituting for $(n-n_1)$ and $(n'-n_1')$, we get

$$\frac{n'-n}{n-1} = \left(1+\frac{\delta}{f}\right)\frac{\lambda'}{\lambda}-1.$$

Again, from Cauchy's equation,

$$(n-1) = a\left(1+\frac{b}{\lambda^2}\right),$$

we obtain

$$\frac{n'-n}{n-1} = \frac{b\left(\dfrac{1}{\lambda'^2}-\dfrac{1}{\lambda^2}\right)}{1+\dfrac{b}{\lambda^2}}.$$

Equating these values, we get

$$b = \lambda^2\left\{\left(1+\frac{\delta}{f}\right)\frac{\lambda'}{\lambda}-1\right\}\Big/\left\{\frac{\lambda^2}{\lambda'^2}-\left(1+\frac{\delta}{f}\right)\frac{\lambda'}{\lambda}\right\}.$$

The quantities to be determined are λ, λ', δ and f.

The two former are known, and the latter are observed as described below.

If the absolute value of the refractive index n be known for any wave-length λ, then by substituting for n, λ and b, we determine a in Cauchy's equation.

Experimental Details.—The optical apparatus used is shown diagrammatically in fig. 1. The straight filament of a Nernst lamp was used as a source of light. The lamp was mounted in a collimator tube so that the filament was vertical and at the focus of the collimating lens. The portion of the filament used was limited by a small circular diaphragm of about 2 mm. diameter placed quite close to it. The collimating tube was supported on an adjustable stand, so that one could thus get a parallel horizontal beam of white light. The brass tube in which the Nernst lamp was mounted was perforated in the neighbourhood of the filament with a ring of holes about 1 cm. in diameter, so that the collimator tube should not get too hot: and radiation from it was prevented from reaching the optical tubes by screens of tin.

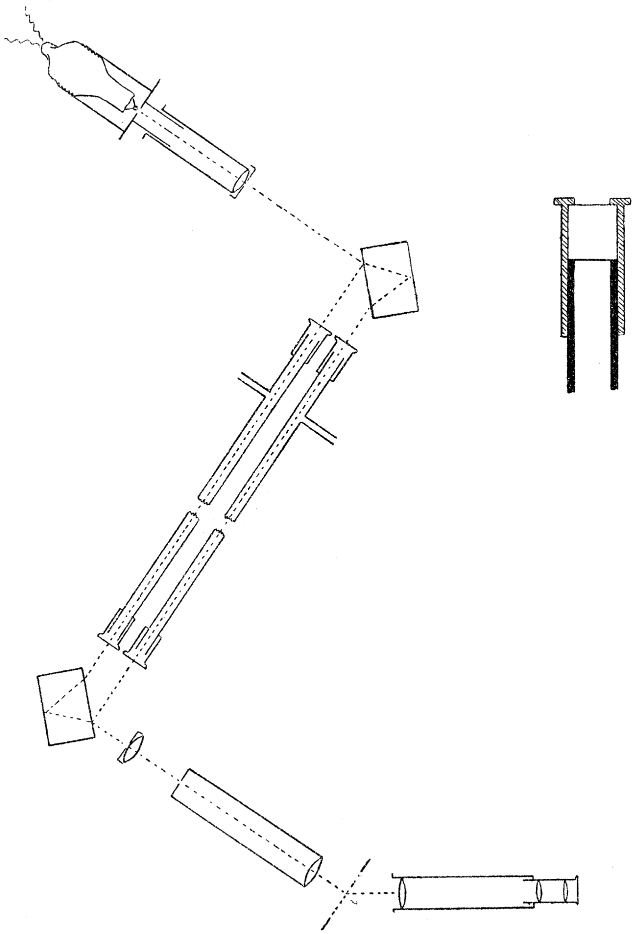

FIG. 1.

Interferometer.—The dimensions of the Jamin plates were 6 × 4 × 3 cm., the reflecting surfaces being 6 × 3 cm. After silvering the back reflecting surface of each plate, each was placed on an adjustable screw stand at a convenient distance apart, so that two horizontal parallel beams of white light passed between them.

The brass tubes to contain the gases were mounted in shallow grooves on an adjustable wooden support, and so placed that one of the reflected beams passed through each tube. The tubes were wrapped in cotton wool, and a thermometer reading to tenths of a degree lay between them. The tubes were 109·95 cm. long and about 0·8 cm. internal diameter. They were closed at each end by worked pieces of plane glass, 1 cm. thick, attached by means of cement. These glass ends were held in place by perforated screw caps also cemented in position, so that the tubes were capable of standing a considerable internal pressure. Into each tube a smaller side tube was screwed and soldered, for attachment to the apparatus for altering the pressure. The tubes and plane glass ends were obtained from Messrs. Adam Hilger and Co. The recombined beam was focussed on the slit of a spectrometer by means of a lens of short focal length. The stands supporting the above, and the source of light, were all on a heavy slate slab built upon brick supports on the ground floor of the laboratory. The apparatus was thus free from vibration and consequent displacement of fringes.

The Analysing Apparatus.—The image of the filament produced by the short-focus lens on the slit of the spectrometer covers only about 1 mm. of the central portion of the length of the slit, so that the spectrum observed, using a plane diffraction grating in the usual way, is narrow in a vertical direction and is crossed by bands. By adjusting one of the Jamin plates these bands can be obtained vertical and at a convenient distance apart. This adjustment is most conveniently made in the first place with a sodium flame as source. By altering the width of the slit, the minima can be made more or less black, and there is a cross wire in the eye-piece of the telescope which can be brought into coincidence with the middle of any one of these dark bands.

Standard Lines in the Spectrum.—These were obtained from a small Plücker tube containing hydrogen, helium, and mercury vapour. By the use of a small reflecting prism a portion of the slit was illuminated by the light from the narrow part of the Plücker tube, when certain well-defined lines of known wave-length could be observed. The lines used were five in number, fairly distributed across the visible spectrum. That there was no measurable error introduced by this means of illumination was shown by using at the same time another similar tube placed directly in front of the slit, when the lines seen were continuous. The standard lines used were the hydrogen red ($6{\cdot}563 \times 10^{-5}$ cm.), helium yellow ($5{\cdot}876 \times 10^{-5}$ cm.), mercury green ($5{\cdot}461 \times 10^{-5}$ cm.), helium green ($5{\cdot}016 \times 10^{-5}$ cm.), and hydrogen blue ($4{\cdot}861 \times 10^{-5}$ cm.).

In determining the absolute refractive index, the sodium D_1 line ($5{\cdot}896 \times 10^{-5}$ cm.) was used, the slit being illuminated directly by a sodium flame, whilst the cross wire was fixed in coincidence with the D_1 line.

Pressure Measurement.—With the tubes used, a change of pressure of 1 atmosphere may cause the transit of about 500 bands in the case of argon, and of about 60 bands in the case of helium. Hence if one wishes to get 300 bands by in the latter case there must be a pressure range of 5 atmospheres, whilst in the former case a range of $\frac{3}{5}$ of an atmosphere will suffice. It was necessary therefore to adopt different methods for altering the pressure in the two tubes.

Argon.—The apparatus used in the case of argon was essentially the same as that adopted by Rayleigh,* for comparing refractivities. It is shown diagrammatically in fig. 2, and the method of changing and measuring the pressure is obvious. The reservoir is of about 500 c.c. capacity, and the manometer limbs of 5 mm. diameter. The reservoir is joined to the optical tubes by compo tubing of 4 mm. bore. This tubing is soldered to the side

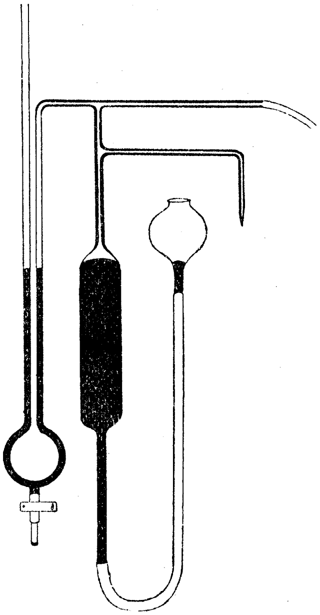

FIG. 2.

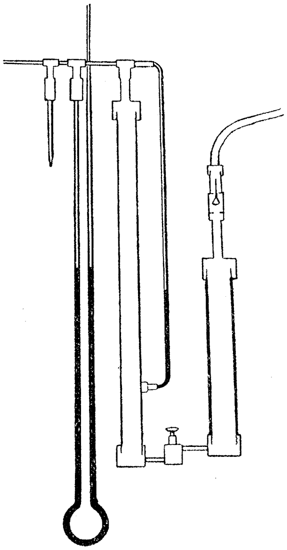

FIG. 3.

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* Rayleigh, 'Roy. Soc. Proc.,' vol. 59, p. 203.

tube of the optical tube, and fastened by sealing wax to the glass tubing leading from the reservoir. Except for the gauge tubing and the end into which the compo tubing is sealed, all the glass tubing is of capillary bore. This, of course, is used to get the maximum pressure change from a given volume (100 c.c. *q.p.*) of gas. The reservoir and optical tube could be exhausted from the side tube, and through this side tube also the gas could be introduced. After the gas is put in, the side tube is sealed off at a constricted part. The pressure was read on a cardboard millimetre scale placed behind the manometer tubes. This scale was glued on to the wooden support and was afterwards tested against a standard brass scale. Over the range of pressure that was to be used, the scale readings were accurate to well within 1/10 mm. Readings were taken on the scale by eye to 1/10 mm. after a rise in both limbs of the manometer had been caused by constricting the pressure tubing below the gauge. Three such readings at least were taken, and the mean value used.

Helium.—The method of changing and measuring the pressure will be seen from an inspection of fig. 3. The longer reservoir, about 105 cm. long and 11 sq. cm. cross section, is connected above with the pressure and indicator gauges, and through compo tubing with the optical tube. Below it is connected through a steel tap with a shorter cylindrical reservoir about 55 cm. long and 18½ sq. cm. in cross section. As much mercury is introduced as will fill the longer reservoir, and about 10 cm. in length of the shorter reservoir. This leaves about 660 c.c. in the longer reservoir to be occupied by the gas at atmospheric pressure. The cylindrical reservoirs were made from ordinary iron steam piping, and the smaller tubing with which mercury would come in contact was of steel; all connections were made by screw-in joints and sealing wax, the latter being melted into the hot thread before screwing the tubes into position. Above, where the mercury did not extend, brass **T**-pieces and tubing were used, and the connections were made by screw-in joints and solder. The glass tubing for gauges was of capillary bore, about 2 mm. diameter, and fastened in position with sealing wax. The internal diameter of the brass or steel tubing into which the glass tubes were fitted was widened for the last 2 or 3 inches, so that the glass tube could just fit in, and so that the end could press up against the ledge formed by the difference in internal diameter. The pressure change was produced by forcing mercury from the shorter reservoir into the longer one. This was done by pumping air into the former. To do this, the valve from a motor tyre was soldered on the top of the shorter reservoir, and a foot pump used for motor tyres enabled a pressure up to 10 atmospheres to be obtained if necessary. The steel tap was then closed and the valve opened. By turning the steel tap now, and slowly reducing the pressure, it was quite easy to count the bands as they moved as slowly as desired over the cross wire. Whilst taking observations for the refractive index, one limb of the manometer gauge was open. The pressure range then measured was about 1300 mm. Readings were taken by eye on a millimetre cardboard scale placed behind the manometer. It was endeavoured to read to 1/10 mm., but as the tubing was of capillary bore and the range considerable, this was not always possible, especially at the lower part of the scale. This degree of accuracy is, however, not necessary, for there was only a transit of 100 bands, and if these were read to one-twentieth of the distance between two bands, the error may be 1 in 2000, and, therefore, the pressure readings need only be taken to ½ mm. to obtain a corresponding degree of accuracy. When experiments for the dispersion were made over a wide pressure range, the open limb of the manometer was sealed. The gas laws were assumed to hold for helium, and the pressure change was not measured, the assumption being that for a range of pressure from 1 to 6 atmospheres the same laws held as from 1 to 3 atmospheres. Before introducing any mercury into the apparatus, air was pumped in till the pressure was about 10 atmospheres, and the whole was placed under water, when no leaks could be discovered. Again, after putting mercury into the reservoirs and manometer, it was pumped up, and readings of the pressure taken on successive days. By this method any leaks could usually be detected, but very small leaks might be obscured by the changes due to temperature. The sealing wax joints were satisfactory, and no leaks were observed from them. On one occasion a leak was found from a solder joint, and on another from the compo tubing which led to the optical tube.

Refractive Index and Dispersion of Argon.—The gas was prepared by Sir Wm. Ramsay and obtained from Messrs. Tyrer and Co. It was introduced directly into the apparatus, after the latter had stood exhausted overnight with a phosphorus pentoxide drying bulb and a small Plücker tube attached, the latter showing that there had been no leak. The reservoir being sealed off, the refractive index and dispersion were determined as below. A typical set of readings taken is given in each case, and later the results of all the other readings made are tabulated and the mean is taken.

Refractive Index.—Pressures were read to 1/10 mm. after causing a rise in both limbs of the manometer, the mean of three such readings at least being taken. The number of bands crossing the standard line was read to one-twentieth of the distance between two bands when possible. As the pressure range used was about 450 mm., and the number of bands about

280, the error in these measurements is probably 1 in 3000. The temperature of the tubes is read to 1/10° C., and in no case did the temperature change by more than 1/10° C. in the course of an experiment which lasted less than 10 minutes. The temperature of the manometer was also observed. The thermometers had previously been compared with a standard thermometer, and for the range of temperature 16° to 19° C., over which these experiments were made, the thermometers agreed to within 1/10° C., so that no connection was necessary for the degree of accuracy aimed at in these determinations. Readings were taken for the refractive index relative to the D_1 line and also to the hydrogen red, as this allowed a check on the accuracy of the measurements, both of the refractive index and of the dispersion.

Dispersion.—The dispersion was found at the same time as the refractive index for the hydrogen red line. The number of fringes between the standard lines was estimated to one-twentieth whenever possible. As the distance apart of the black bands and their breadth vary considerably with the pressure, it is not possible to read with the same degree of accuracy always. The bands were used when as far apart as possible over the pressure range employed. This, of course, is attained by preliminary adjustment of the Jamin plates, and subsequent alteration of pressure in the other optical tube if necessary. The results obtained are given below.

The following is a typical series of experiments:—

Refractive Index of Argon for D_1 line. Tuesday, July 30, 1907.

Time, 3.47. Temperature of tubes, 16°·65 C. Temperature of manometer, 17°·5 C.

Pressure.

Initial.				Final.			Difference.
474·5	475·3	476·2	477·0	708	709·5	710·1	494·0
458·8	459·5	460·5	461·3	214	215·5	216·0	15·7
15·7	15·8	15·7	15·7	494	494·0	494·1	478·3

Number of bands crossing D_1 line and direction = 313·7, to right.

Time, 3.55. Temperature of tube, 16°·7 C. Temperature of manometer, 17° C.

Substituting the values below in

$$(n_0-1) = (1+at)\,.\,760\,.\,\frac{f\lambda}{\mathrm{PL}},$$

$a = 0·00367$ $\lambda = 5·896 \times 10^{-5}$ cm.
$t = 16°·7$ C. $\mathrm{P} = 478·3$ mm.
$f = 313·7$ $\mathrm{L} = 109·95$ cm.,

we get $n_0 = 1·0002837$,

where n_0 is the refractive index at 0°, 760 mm. pressure, for the D_1 line.

Dispersion in Argon and Refractive Index for H red. Tuesday, July 30, 1907.

Time, 4.4. Temperature of tubes, 16°·7 C. Temperature of manometer, 17° C.

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Pressure.

Initial.				Final.					Difference.
710	708	709·5	710·1	477	477·2	474·0	474·5	475·5	494·00
216	214	215·5	216·0	461	461·2	457·9	458·2	459·5	16·08
494	494	494·0	494·1	16	16·0	16·1	16·3	16·0	477·92

Number of bands crossing H red and direction = 280·95 to left.

Number of Bands between Standard Lines and H red.

H red.	He yellow.	Hg green.	He green.	H blue.
Initially 0	39 ·6	68 ·65	105 ·55	119 ·9
0	39 ·6	68 ·6	105 ·45	119 ·85
Mean 0	39 ·6	68 ·63	105 ·5	119 ·87
Finally 0	5 ·8	10 ·07	15 ·45	17 ·55
0	5 ·8	10 ·03	15 ·5	17 ·55
Mean 0	5 ·8	10 ·05	15 ·47	17 ·55

Time, 4.30. Temperature of tubes, 16°·72 C. Temperature of manometer, 17°·5 C.

This gives n_0 = 1·0002830 for the H red line at 0° and 760 mm.; also for δ the diminution in the number of fringes between the H red and the standard lines above, when f bands cross the H red,

we get δ	0	32·8	58·57	90·03	102·32,
whence $\left(1+\frac{\delta}{f}\right)$	0	1·1203	1·2085	1·3205	1·3642.

Results.

Refractive Index of Argon at 0° and 760 mm. for D_1 line.

Date.	Temperature (t).	Pressure change (P).	No. of bands (f).	n at 0° and 760 mm.
Friday, July 26 ……………	17 ·5	439 ·8	287 ·6	1 ·0002836
	17 ·6	439 ·4	287 ·2	2836
	17 ·8	438 ·65	286 ·65	2837
Saturday, July 27 …………	16 ·95	435 ·75	285 ·5	2836
	17 ·05	437 ·03	286 ·4	2838
	17 ·2	242 ·13	158 ·55	2837
Monday, July 29 …………	17 ·8	480 ·0	313 ·5	2836
	17 ·9	479 ·1	312 ·8	2836
	18 ·0	479 ·9	313 ·25	2836
Tuesday, July 30 …………	16 ·5	477 ·2	313 ·2	2837
	16 ·63	478 ·35	313 ·65	2835
	16 ·7	478 ·3	313 ·7	2837
Friday, August 9 …………	18 ·75	362 ·2	236 ·0	2838
	18 ·9	565 ·6	368 ·2	2837
	18·9	203 ·25	132 ·25	2837
			Mean ……	1 ·0002837

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Refractive Index of Argon at 0° and 760 mm. for H red.

Date.	Temperature (t).	Pressure change (P).	No. of bands (f).	n at 0° and 760 mm.
Friday, July 26	17·92	438·45	256·7	1·0002830
Saturday, July 27	17·4	480·15	281·45	2829
	17·6	438·65	257·14	2830
Monday, July 29	18·1	480·0	280·65	2829
	18·2	479·3	280·1	2828
Tuesday, July 30	16·72	477·92	280·95	2830
	16·75	477·4	280·54	2829
Friday, August 9	19·0	352·9	205·8	2830
			Mean	1·0002829

Dispersion in Argon, $1+\frac{\delta}{f}$.

Date.	f.	He yellow.	Hg green.	He green.	H blue.
Friday, July 26	256·7	1·1202	1·2082	1·3204	1·3642
Saturday, July 27	281·45	1·1206	1·2085	1·3206	1·3639
	257·15	—	—	—	1·3642
Monday, July 29	280·65	1·1206	1·2090	1·3207	1·3651
	280·1	1·1206	1·2086	1·3205	1·3644
Tuesday, July 30	280·95	1·1203	1·2085	1·3205	1·3642
	280·54	1·1205	1·2085	1·3208	1·3648
Friday, August 9	205·8	1·1206	1·2090	1·3202	1·3645
Mean $\left(1+\frac{\delta}{f}\right)$		1·1205	1·2086	1·3205	1·3644

To find b we reduce as below, where λ refers to the H red line ($6{\cdot}563\times10^{-5}$ cm.), λ' to the other standard lines.

	He yellow.	Hg green.	He green.	H blue.
λ'	$5{\cdot}876\times10^{-5}$ cm.	$5{\cdot}461\times10^{-5}$ cm.	$5{\cdot}016\times10^{-5}$ cm.	$4{\cdot}861\times10^{-5}$ cm.
$\left(1+\frac{\delta}{f}\right)$	1·1205	1·2086	1·3205	1·3644
$\left(1+\frac{\delta}{f}\right)\frac{\lambda'}{\lambda}$	1·0032	1·0057	1·0093	1·0106
$\frac{n'-n}{n-1}$	0·0032	0·0057	0·0093	0·0106
b	$5{\cdot}6\times10^{-11}$	$5{\cdot}6\times10^{-11}$	$5{\cdot}7\times10^{-11}$	$5{\cdot}6\times10^{-11}$

Mean $b = 5{\cdot}6\times10^{-11}$.

Taking $$(n-1) = a\left(1+\frac{b}{\lambda^2}\right),$$

and substituting $$b = 5\cdot 6\times 10^{-11},$$

$$n = 1\cdot 0002837 \text{ for } D_1 \text{ line},$$

$$\lambda = 5\cdot 896\times 10^{-5} \text{ cm.},$$

we get $$a = 0\cdot 0002792;$$

therefore $$n = 1\cdot 0002792+\frac{1\cdot 6\times 10^{-14}}{\lambda^2}.$$

Helium.—This was prepared from thorianite. The thorianite was placed in one half of a porcelain tube, the other half containing copper oxide. The tube was attached to a mercury pump, and through a tube containing solid caustic potash to a gas collector full of boiled caustic potash solution. There was also a mercury gauge to indicate the pressure in the apparatus. After exhausting and shutting off the pump, the porcelain tube was heated in a combustion furnace until the pressure indicated by the manometer was just above atmospheric pressure. Connection with the collecting reservoir was then made, and the gas slowly accumulated in it. In this manner about 1 litre of helium was collected. The thorianite being heated at atmospheric pressure, the helium comes off very slowly, but any hydrogen present should, under these conditions, be removed by the red-hot copper oxide. The gas was introduced about 200 c.c. at a time into the exhausted reservoir attached to the optical tube. Before entering the reservoir, the gas was passed through a drying tube of calcium chloride and a tube of charcoal surrounded by liquid air, each portion of the gas being kept in contact with the charcoal for half an hour before being passed on to the reservoir. A Plücker tube attached to the mercury pump, and arranged before the slit of the spectrometer, enabled one to test the gas spectroscopically from time to time. No trace of foreign gases could be observed. After sufficient gas had been introduced to give the required pressure range, the reservoir containing it was sealed off, and the experimental results given below were obtained.

Refractive Index.—The pressure range being 1300 mm., it is not necessary, as stated before, to read to more than $\frac{1}{2}$ mm. to get an accuracy of 1 in 2000, though readings were attempted to 1/10 mm. The number of bands crossing the standard line used was about 100, so that to get the same degree of accuracy it is necessary to read to one-twentieth of the distance between two bands. As it was possible in the case of helium always to start and end with the cross wire coincident with a standard line and with the middle of a black band, I consider this accuracy was obtainable. It may be remarked here that with gases of small refractive power like helium the accuracy of the value for the refractive index depends largely on the accuracy with which the number of bands that cross the standard line can be estimated; for with the same pressure range in helium only one-eighth the number of bands will cross the same standard line as in the case of air or argon. It will be observed below that the value of the refractive index shows a slight increase from day to day, whilst the values agree well on any single day. This slight increase was, I think, due to a small air leak. If, in the course of the three days over which the experiments were made, an air leak of 1 in 2500 had occurred, the variation observed would be accounted for. The same increase is observed in the value for the H red line, and the same agreement on any one day. That the increase was less from Tuesday to Wednesday afternoon is accounted for by the fact that when the gas was put in I arranged the level of the mercury in the reservoir so that after sealing off and opening the tap connecting the reservoirs the gas should be under pressure slightly greater than atmospheric. The barometer rose on Tuesday night and the temperature fell, so that the observed fall in pressure on Wednesday morning might very possibly have been due to these changes; and that this was largely the case is shown by the results obtained on Wednesday afternoon. The gas, however, was left on Wednesday afternoon under slightly less than atmospheric pressure, and subsequent readings taken at night showed on reduction a decided but small increase in the refractive index. Again on Thursday morning an increase was observable. The values therefore obtained on Tuesday, soon after the gas was put in, and on Wednesday afternoon, are probably most correct. It will be seen that the extreme values for the refractive index obtained during the three days do not differ by more than 1 in 350, so that the readings for the dispersion were not measurably altered by the change in the refractive index. As in the case of argon, measurements of the refractive index for the D_1 line and the H red were made, and a summary of the results is given below.

Dispersion.—In some of the experiments the open limb of the manometer was sealed off, and the pressure change arranged so that about 250 bands crossed the H red line. As in the case of argon, the bands were estimated to one-twentieth when possible, and the fringes used when the bands were as far apart as possible over this pressure range. There is no great advantage in having a larger number of bands than 250 crossing the standard line, for the bands get so close together in the blue and green that it is difficult to measure them accurately, and what is gained in accuracy in the measurement of f is lost in the measurement of δ.

Refractive Index at 0° *and* 760 *mm. for* D_1 *line.*—The observations were taken and reduced in a similar manner to those of argon, except that the scale reading of the manometer used was the result of one observation only and not the mean of several.

Refractive Index of Helium at 0° and 760 mm. for D_1 line.

Date.	Temperature (t).	Pressure change (P).	No. of bands (f).	n at 0° and 760 mm.
Tuesday, August 6…………	18·8	1245·9	100·1	1·00003500
	18·7	1244·5	100	3499
Wednesday afternoon, August 7	16·1	1232·7	100	3501
Wednesday night, August 7	16·25	1230·8	100	3509
	16·25	1230·2	100	3510
	16·3	1230·7	100	3510
Thursday, August 8 ………	17·1	1232·7	100	3514
	17·2	1233·6	100	3512
	17·3	1233·4	100	3514
	17·4	1283·9	104	3512

As explained above, the value most probably correct is 1·00003500, the mean of the first three observations.

Refractive Index of Helium at 0° and 760 mm. for H red.

Date.	Temperature (t).	Pressure change (P).	No. of bands (f).	n at 0° and 760 mm.
Tuesday, August 6…………	18·4	1315·6	95	1·00003497
Wednesday night, August 7	16·4	1289·9	94	3505
	16·4	1303·6	95	3505
Thursday, August 8 ………	16·7	1357·8	99	3510
	16·8	1318·5	96	3507
	17·0	1345·3	98	3511

Dispersion in Helium, $1+\frac{\delta}{f}$.

Where the number of bands crossing the H red line was greater than 100, the open limb of the manometer was sealed off and the pressure was not read.

Date.	*f*.	He yellow.	Hg green.	He green.	H blue.
Wednesday, August 7	100	1·1185	1·2053	1·3130	1·3560
	94	1·1195	1·2055	1·3135	1·3558
	95	1·1184	1·2045	1·3137	1·3558
Thursday, August 8 ...	99	1·1177	1·2040	1·3131	1·3550
	96	1·1192	1·2041	1·3125	
	98	1·1179	1·2034	1·3127	1·3551
	250	1·1182	1·2046	1·3132	1·3560
	101	1·1183	1·2040		
	99	1·1177	1·2040	1·3131	1·3565
	200	1·1177	1·2040	1·3127	1·3551
	250	1·1180	1·2043	1·3132	1·3557
	250	1·1186	1·2050	1·3139	1·3566
	250	1·1179	1·2041	1·3129	1·3558
Mean $1+\frac{\delta}{f}$		1·1183	1·2044	1·3131	1·3557

To find *b*.—Reducing these values as for argon, λ referring to the H red line ($6·563 \times 10^{-5}$ cm.), we get :—

	He yellow.	Hg green.	He green.	H blue.
λ' in cm.	$5·876 \times 10^{-5}$	$5·461 \times 10^{-5}$	$5·016 \times 10^{-5}$	$4·861 \times 10^{-5}$
$1+\frac{\delta}{f}$	1·1183	1·2044	1·3131	1·3557
$\left(1+\frac{\delta}{f}\right)\frac{\lambda'}{\lambda}$	1·0012	1·0022	1·0036	1·0041
$\frac{n'-n}{n-1}$	0·0012	0·0022	0·0036	0·0041
b	$2·1 \times 10^{-11}$	$2·1 \times 10^{-11}$	$2·2 \times 10^{-11}$	$2·2 \times 10^{-11}$

Mean $b = 2·2 \times 10^{-11}$.

Taking $$n-1 = a\left(1+\frac{b}{\lambda^2}\right),$$

and substituting
$$b = 2·2 \times 10^{-11}$$
$$n = 1·00003500 \text{ for } D_1 \text{ line,}$$
$$\lambda = 5·896 \times 10^{-5} \text{ cm.,}$$

we get $$a = 0·00003478;$$

therefore $$n = 1·00003478 + \frac{7·6 \times 10^{-16}}{\lambda^2}.$$

Discussion of Results.

Argon.—The value obtained for the refractive index for D_1 line is 1·0002837. Ramsay and Travers* give the refractive power (air = 1) as 0·968 for the brightest part of the spectrum. If air be taken as 1·0002922 for the mean D line (Kayser and Runge†), this makes argon to be 1·0002828. Ramsay and Travers used a pressure range of about 500 mm., corresponding to a transit of between 30 and 40 bands. The pressure range used above is about the same, but corresponds to a transit of nearly 300 bands. The results agree to 1 in 300, and closer agreement can hardly be expected, for if the refractive index of air for the brightest part of the spectrum be taken as 1·000293, the results are practically identical.

The dispersion of argon is slightly less than that of air, if the coefficient b for air be $5·8 \times 10^{-11}$ as found by Mascart.‡

Helium.—The value of the refractive index for the D_1 line is 1·00003500. Ramsay and Travers give the refractive power (air = 1) as 0·1238, and if air be taken as 1·0002922, this gives a value for helium of 1·0000361, which is considerably larger than that obtained above. Assuming that Ramsay and Travers used the same apparatus as for argon, the same pressure range would correspond to a transit of between 4 and 5 bands only in the case of helium. Hence the accuracy of the value of the refractive power will depend largely on the accuracy with which, after a change of pressure, the middle of the movable band can be brought back into continuation with the middle of the fixed band used as a fiducial line. Ramsay and Travers considered that they could estimate to 1/25 of a band, so that the error of the setting may be 1 in 100. The accuracy of their pressure measurements was increased by comparing the refractive power of helium with that of hydrogen, and then that of the latter with air. By this means the bands were kept in position in the field of view over a wider range of pressure than was possible when helium was compared directly with air. The difference in the value obtained by Ramsay and Travers and that obtained above may perhaps be attributed to the fact that the pressure changes in the experiments of the former compensate for the transit of so small a number of bands, though a difference of 3 per cent. in the refractive power is more than one might expect.

The dispersion is, as will be seen, much smaller than that of any other gas so far examined, the coefficient b being almost exactly half that found by Mascart in the case of hydrogen.

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* Ramsay and Travers, 'Roy. Soc. Proc.,' vol. 67, p. 331.

† Kayser and Runge, 'Abh. d. Berl. Akad.' (1893).

‡ Mascart, 'Ann. de l'École Normale' (1877).

The results for argon and helium are tabulated below, and, for comparison, Mascart's values for hydrogen are also given.

Refractive Index, reduced to 0° C. and 760 mm. pressure for D_1 line.

Argon	1·0002837
Helium	1·00003500
Hydrogen (Mascart)*...	1·0001387

Dispersion :—In equation

$$n-1 = a\left(1+\frac{b}{\lambda^2}\right), \quad \text{or} \quad n = \mathrm{A}+\frac{\mathrm{B}}{\lambda^2},$$

	b.	*a*	A.	B.
Argon.........	$5{\cdot}6\times10^{-11}$	0·0002792	1·0002792	$1{\cdot}6\times10^{-15}$
Helium	$2{\cdot}2\times10^{-11}$	0·00003478	1·00003478	$7{\cdot}5\times10^{-16}$
Hydrogen ... (Mascart)†	$4{\cdot}3\times10^{-11}$	0·0001376	1·0001376	$5{\cdot}9\times10^{-15}$

It may be noted that the values of a/b for these substances are approximately in the ratio 3 : 1 : 2.

I wish to thank Professor J. J. Thomson for suggesting this work to me and for the interest he has taken in it. My thanks are also due to Mr. C. T. R. Wilson, to whom I am much indebted for advice in all that pertains to the optical part of this work.

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* *Loc. cit.*

† *Loc. cit.*